TITLE:(U) LUCIE - LASER ENHANCED UNDERWATER CAMERA WITH DIODE-PUMPED, SOLID-STATE LASER, DOUBLE STAGE MICRO-CHANNEL GATED CCD & MOTORIZED IRIS, FOCUS, ZOOM WITH VARIABLE FOCAL LENGTH

PERSONAL AUTHOR: Fournier, G.R.; Bonnier, D.; Forand, J.L.; Pace, P.W.

CORPORATE AUTHOR: Defence Research Establishment Valcartier, Valcartier QUE (CAN)

ABSTRACT: (U) Following this tradition, six years ago our laboratory built a device to do accurate measurements of the optical absorption and scattering of seawater. We were traying to fill a serious gap in the database on the optical properties of seawater in the arctic and off the coasts of Canada. The device, called NEARSCAT, was deployed at sea during several cruises. As more and more data accumulated, one fact became clear: coastal waters scatter light much more than they absorb it. In othter words, the water is foggy. Light still penetrates deeply into the seawater, but it is diffused. This means that the unconventional imaging technique of range-gated laser imaging would indeed provide a significant viewing methods in a real sea environment.

DESCRIPTORS: (U) Underwater cameras;Underwater photography;Sea water;Optical properties;Solid state lasers;Charge coupled devices

IDENTIFIERS: (U) Range gated laser imaging;LUCIE;NEARSCAT

REPORT DATE: 19 Oct 1994 **NUMBER OF PAGES :** 4

Reprints: Sea Technology Magazine

DRDKIM N°: 95-04156 **CANDIS N°:** 150790 **Format(s):**Document Image stored on Optical Disk;Hardcopy

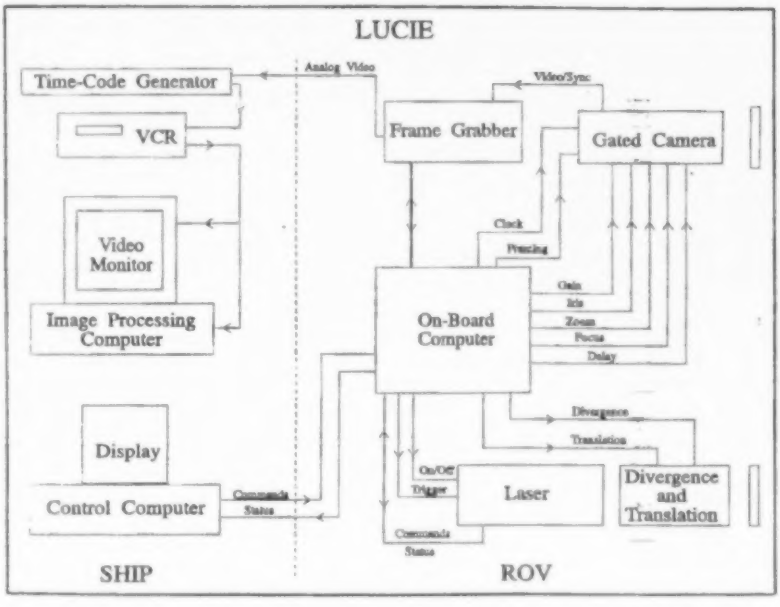
Date modified: 2003-04-17

P150790.PDF [Page: 3 of 14]

LUCIE—Laser Enhanced Underwater Camera

With Diode-Pumped, Solid-State Laser, Double Stage Micro-Channel Gated CCD & Motorized Iris, Focus, Zoom with Variable Focal Length

By Dr. George R. Fournier
Project Leader
Denis Bonnier
Research Scientist
Dr. J. Luc Forand
Research Scientist
and
Dr. Paul W. Pace
Head, Electro-Optic Warfare Section
Defence Research Establishment, Valcartier
Courcelette, Quebec, Canada



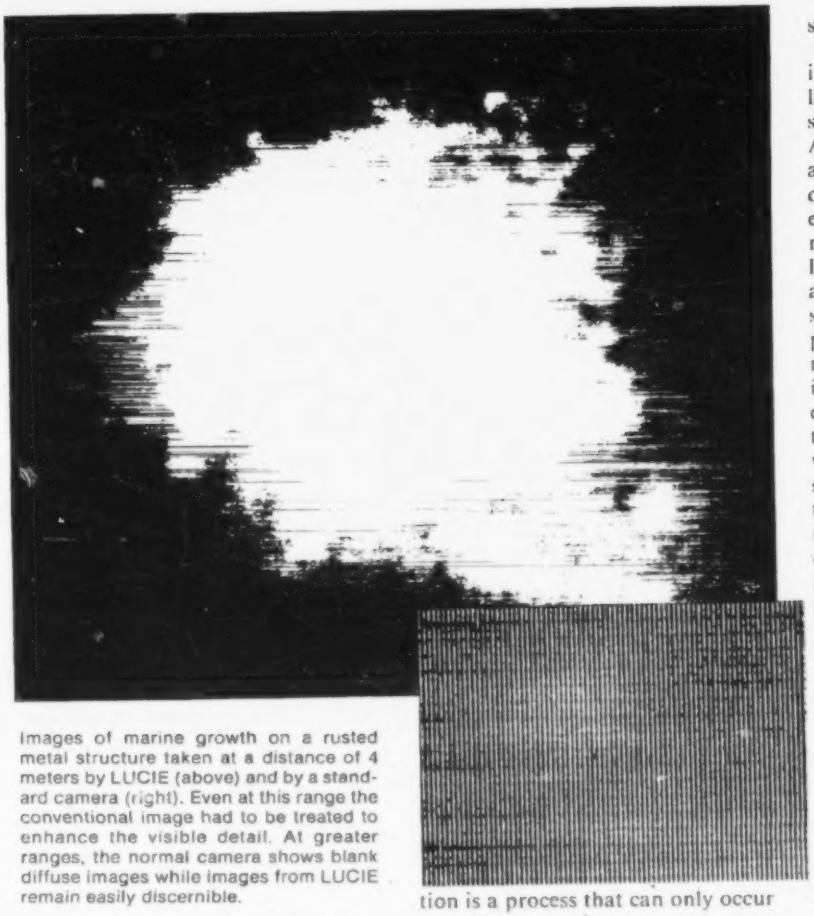
LUCIE laser range-gated system is mounted with its tilt and pan head on the front of the Hysub 5000 ROV. The laser is housed in the left cylinder, the camera is in the central cylinder, and the computer and control electronics are in the right cylinder. Above, video is sent to the surface through a digital frame-grabber. Commands and status information are exchanged over a separate line by the shipboard control computer and the onboard LUCIE computer. The divergence and translation unit (zoom lens) lines up the laser with the camera and zooms the laser beam to match the camera zoom setting.

For a creature whose main sensory input is visual, working underwater can be a very frustrating experience. Visibility can range from nil, at worst, to a few tens of meters at best. Even for carrying out work at relatively short distances, we have had to rely on sonar input; but, being human, we are still most comfortable with a picture. This is why ever since the Second World War there has been a distinguished, continued scientific effort aimed at understanding and improving underwater visibility.

Following this tradition, six years ago, our laboratory built a device to

Reprinted from
***SEA TECHNOLOGY* magazine**

P150790.PDF [Page: 4 of 14]



Images of marine growth on a rusted metal structure taken at a distance of 4 meters by LUCIE (above) and by a standard camera (right). Even at this range the conventional image had to be treated to enhance the visible detail. At greater ranges, the normal camera shows blank diffuse images while images from LUCIE remain easily discernible.

do accurate measurements of the optical absorption and scattering of seawater. We were trying to fill a serious gap in the database on the optical properties of seawater in the arctic and off the coasts of Canada. The device, called NEARSCAT, was deployed at sea during several cruises. As more and more data accumulated, one fact became clear: coastal waters scatter light much more than they absorb it. In other words, the water is foggy. Light still penetrates deeply into the seawater, but it is diffused. This means that the unconventional imaging technique of range-gated laser imaging would indeed provide a significant improvement over conventional viewing methods in a real sea environment.

Throwing Light Around

In the ocean, light can either be absorbed by the water and the particles floating in it or be scattered in a direction other than the one from which it came. For a photon, absorption is a process that can only occur once, but scattering can occur many times. If the probability of scattering is stronger than the probability of absorption, a photon will undergo—on the average—many changes of direction before it is finally absorbed. Light that was originally emitted in one direction will slowly diffuse out. Ultimately it will appear to come from all directions with an almost equal intensity. This is exactly what happens in a fog.

When it occurs in daytime, there is still plenty of light but it comes almost equally from all directions. Most of us have had the unfortunate experience of driving at night in such a fog. We are often blinded by the light scattered back toward us from our own headlights by the surrounding fog banks. We can still often clearly see the headlights or tailights of other cars. It would be very nice indeed to be able to send our own headlights ahead of us to illuminate the road back toward us.

Range-gated laser imaging is a method that can provide us with just such a virtual light source.

The principle of range-gated laser imaging is elegantly simple. A short laser pulse of several nanoseconds is sent out to flood-illuminate an area. A gated intensified camera looks out at this same area. After a given time delay, the camera is gated on for several nanoseconds and an image is recorded. During the delay the laser light has time to travel to the target and return to the camera. All the scattering that occurred while the pulse was going out to the target has not been recorded by the camera, as it was closed during this time. To the camera, the illumination now seems to come from a volume (or slice) of water whose depth is equal to half the sum of the laser pulse and gate-on times multiplied by the speed of light in water. This slice is located at a distance equal to half the delay time between the laser and the gate multiplied by the speed of light in water. The factor of one-half is needed to account for the round trip time. By varying the delay time between the laser pulse and the camera gate opening, one can move the illuminated slice either away or toward the camera in controlled steps.

Here's *LUCIE*

The principle of range-gating has been known for many years. However, it is only recently that the technology for the various components evolved sufficiently to allow the building of reliable systems that can operate on ROV power budgets.

In the past, the weak link in the system was the laser source. This situation has changed radically since the arrival of diode-pumped all-solid-state laser systems. These systems are more compact and have a much higher overall efficiency than their predecessors. They are also inherently very reliable. We have operated one such system—both in the laboratory and in the ocean—for more than 1,500 hours. LUCIE (an acronym for laser underwater camera image enhancer) was specifically designed to take advantage of this new technology.

LUCIE is mounted on the front of the Hysub 5000, an ROV belonging to Canada's Institute of Ocean Sciences. The system is housed in three cylinders, each 30 centimeters in diameter by 60 centimeters in length. These cylinders are interconnected and bolted to a frame that is attached to the ROV through hydraulic linkages.

P150790.PDF [Page: 5 of 14]

This allows the camera to be tilted and panned with respect to the vehicle.

The entire assembly is neutrally buoyant to reduce the load on the ROV. The left cylinder contains the laser system; the camera is housed in the adjoining cylinder and the computer and control electronics are in the third cylinder. The cylinders are filled with nitrogen to avoid condensation on the optical surfaces.

The system is designed to be submerged up to 200 meters. The peak start-up power consumption of LUCIE is 600 watts and the mean operating power is 400 watts. We emphasize that no particular care was taken to compactly package LUCIE and that its size can be considerably reduced.

The laser source is a 2,000-pulse-per-second diode-pumped Nd:YLF device. It has a pulse length of 7 nanoseconds with an average power of 0.5 watt in the green. The green laser beam passes through a zoom lens system and is sent out in the shape of a cone with an apex angle that can vary from 3° to 30° depending on the zoom setting.

The light is collected by a 7-centimeter-diameter zoom lens. The lens has a continuously variable focal length from 11 to 110 millimeters and its iris, focus, and zoom are motorized. The camera is a double-stage microchannel plate intensified gated CCD (charged coupled device) with interline transfer.

To minimize noise, the CCD is kept at -20°C by a double stage electrical Peltier cooler. The gain of the intensifier can be continuously varied from 500 to 1 million. The width of the camera's gate is also 7 nanoseconds, a good match for the laser's pulse length. The delay between the laser pulse and the gate pulse can be varied in increments of 1 nanosecond. These settings produce an illuminated volume with a depth of 1.5 meters that can be moved in 10-centimeter steps.

In operation we set the focus of the camera at the distance of the illuminated volume and adjust the zoom setting of the laser to match the zoom setting of the camera.

Operating at the normal video rate of 30 frames per second, each camera frame is the sum of images produced by 66 laser and gate pulses. This image integration noticeably improves the quality of the resultant image as it averages out the laser's speckle. To ensure the recording and display of this high quality image, the analog video link between the ROV and the ship was designed to maintain a bandwidth exceeding the fidelity required by the super VHS recording system used onboard the ship.

All of LUCIE's underwater and on-ship functions are monitored and controlled by two single-board, IBM-compatible computers. LUCIE is also equipped with a digital frame grabber that can operate in either normal pass-through mode (30 frames per second) or in slow-scan mode. In the latter mode, the camera CCD clock can be slowed down and image frames taken at different programmable rates. This is equivalent to averaging several frames before display.

Since 1991, the system has been operated at depths of up to 70 meters in water whose temperature varied from 5° to 35°C. The system has been extremely reliable. Operations have been carried out for periods of several weeks without having to open the system for maintenance. Dives have never been interrupted because of a camera malfunction.

In the murky waters characteristic of harbors and their approaches, the range-gated camera can identify objects at three to five times the distance of a standard intensified camera with 500-watt floodlights. LUCIE could see objects at distances of 12 to 15 meters that the standard camera could not distinguish beyond 3 meters.

In a standard camera, the main effect of scattering is to reduce the contrast. Consequently, LUCIE's performance edge shows to more advantage when viewing inherently low-contrast targets, even though the absolute range of visibility is greater for high-contrast targets.

A comparison between LUCIE and a standard camera with a low-contrast target was made. The LUCIE images showed plant life growing on a rusting barrel at a range of 4 meters. We took such a close-up picture for comparison because at greater ranges where LUCIE can still record clear images, all that a standard camera shows is a blank screen.

For demonstration purposes, we have repeatedly performed sonar to camera hand-offs of a variety of targets. Using images from LUCIE, we have also maneuvered the ROV around objects that were well beyond the visibility range of a standard camera. In terms of reliability and performance, the camera has greatly exceeded our initial expectations.

One Way, Toll-Free

We were at first surprised by the performance of the LUCIE system. Fortunately, we had always measured the amount of absorption and scattering of the seawater with our NEARSCAT instrument. With this data we have been able to make a model that accurately predicts the performance of range-gated imaging systems. The model showed us that there were two not-so-obvious effects that come into play in such systems.

The first of these effects comes from the fact that in seawater, scattering occurs mainly in the forward direction. Photons are deflected from their original paths by very small angles. Thus, a beam of light will broaden very gradually as it propagates through water.

In range gating, we generally want to illuminate over a large angle with the laser. Since broadening of the beam by scattering occurs slowly, we can compensate for it by narrowing the original angular size of the laser beam. In this way we can ensure that we use all the laser light to illuminate only the area looked at by the camera. Therefore, the amount of laser light lost on the way to the target depends only on the amount of absorption.

The great majority of interesting underwater targets have dull surfaces. Such surfaces will reflect the light almost equally in all directions. Some of this diffuse reflected light comes back toward the camera and is collected by the lens. However, most of the photons that are scattered on their way to the lens do not reach the lens so that the amount of light lost on the way back to the camera depends on the sum of the absorption and the scattering.

In the full two-way process, the amount of light that we can detect with a range-gated camera is twice as sensitive to the amount of absorption as it is to the amount of scattering.

We have found that in waters typical of harbors and their approaches, the amount of absorption is less than the amount of scattering. This can also be true near the sea bottom. Laser range-gated cameras perform particularly well in such environments. In fact, as long as we match the laser illumination with the field-of-view of the camera, we have found that the performance in terms of range of visibility remains the same.

P150790.PDF [Page: 6 of 14]

This is at first glance counterintuitive. How can we illuminate a larger area with the same amount of light and still see the same distance?

The solution to this apparent paradox is simple. Let us say we first view a 10-centimeter square with a camera set for a given field-of-view. Then, after doubling the camera's field-of-view and the area illuminated by the laser, we look at the same square. The amount of laser radiation intercepted by the square will be reduced by a factor of four while the image of the square on the monitor screen and therefore on the camera's CCD detector will, at the same time, be reduced by the same factor of four.

The detector response is proportional to intensity, which is the ratio of the amount of light received divided by the area over which it is received.

Since both parts of this ratio are reduced by the same factor, the ratio itself remains unchanged and the detector response is the same in both cases. Even though we have doubled the field-of-view and the angle of illumination of the laser, the signal at the camera remains the same.

The CCD detector is an array of many small detectors. As long as an object's image on the detector array is larger or equal to a single detector, the signal from that object will have the same intensity independent of the field-of-view of the system. The only other necessary condition for this to be true is that the laser's illumination match the field-of-view of the camera at all times. This means that we can increase the field-of-view of the range-gated system without paying any penalty in terms of operational range. The practical limit comes from the fact that larger field-of-view lenses have smaller diameters and therefore collect less total light.

We have operated LUCIE almost entirely in a manual mode to precisely specify various parameters and to study their effects.

We are now in the process of fully automating the camera and are using modern image processing techniques to enhance the images. These techniques will both increase the range at which objects can be identified and improve the quality and resolution of the pictures presented.

LUCIE has already proven that reliable systems with reasonable power consumption can be built by using current laser technology. Laser range-gated imaging provides a significant increase in the range of visibility. This translates into a substantial saving in the time taken to carry out ROV missions. *AU*

Dr. George R. Fournier received his bachelor's degree in aerospace engineering from Princeton University (1971), master's in applied science from the University of Toronto (1972), and doctorate in physics from Imperial College (London) in 1976. With DREV since 1977, his current interests are scattering theory, laser sources, and underwater electro-optical systems.

Denis Bonnier graduated from Laval University in 1979 and received his master's degree in electrical engineering in 1981. He then joined DREV where he primarily worked on laser rangefinder development and applications. Bonnier's present interests include active imaging, vision, and underwater optics.

Dr. J. Luc Forand, with DREV since 1989, has current interest in underwater imaging, light scattering, and atmospheric optical effects in the marine environment. He spent a year as a NSREC post-doctorate fellow at the Joint Institute of Astrophysics (Boulder, Colorado). Forand received his bachelor of science degree from Dalhousie University (1981), his master's from the University of Western Ontario (1983), and doctorate from the University of Windsor (1986) where he spent a year as a post-doctoral fellow.

Dr. Paul W. Pace joined DREV in 1974 after receiving his doctorate from the University of Windsor. His work initially concerned CO_2 laser development. After becoming leader of the Lasers and Applications Group, Pace's research continued in the area of solid-state lasers and non-linear optics leading to research activities including remote sensing, active imaging, and underwater optics.